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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Shoe Machinery and Its Lubrication

Flow of Oil in Pipes

PUBLISHED MONTHLY BY
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Shoe Machinery*

NOT many years ago shoe making was practically a one-man job. Now a pair of shoes, in order to be made up to modern perfection, often has to pass through as many as 210 pairs of hands, and there may be as many as 170 machine operations on it before it is finished. But in spite of the variety of operations and the number of machines employed, production efficiency has greatly increased. A modern plant turning out about 20,000 pairs of shoes a day, requires about 2,000 employes, though of course the number may differ somewhat, depending on character, finish and style of shoe. Nevertheless, when this is compared with the time required by an old-time shoemaker to cut out and sew up a pair of shoes by hand, the great strides made during the last few years in rapid production are easily realized.

This is only a small part of the story, however. A comparatively few years ago, shoes were all made alike with no rights or lefts, and there were only two widths, stouts and slims. A stout last was made by fitting a pad over the slim last. The breaking in of a pair of shoes was quite a dreaded major operation, and one postponed as long as possible. Today, if you keep to the same last, you can put on a new pair of shoes and wear them without discomfort except for a little stiffness. The comfort of a correct fitting shoe is now within the reach of all instead of, as formerly, a thing that could only be enjoyed by the rich. This has been accomplished in a few years by means of a large number of interesting man-replacing machines and the division of work by efficient organizations. These machines are designed to operate accurately and quickly, for although the shoe operator is usually on a piece work basis and any lack of application on his part might at first sight seem to be his own concern, nevertheless the operating company has an investment in him and the plant, and it is essential that every assistance possible be given to produce accurate work and do it rapidly. This has resulted in the development of intricate machines with large numbers of small moving parts so that just the proper action is given and it is done accurately without lost motion. To attain this efficiency, however, these machines must be properly lubricated, for a gummy or tight bearing may not only slow down operation or put the machine and others depending on it out of commission, but also may cause the production of inaccurate and unsalable work. We will discuss the various machines used in shoe making, and the proper oils to use in order to give them efficient lubrication.

General

The process of shoe making can be divided into several distinct general operations which may be differentiated by the different rooms or departments in which they are carried on. First the leather and linings are cut to proper size, then stitched together to form the upper. The

*Appreciation is expressed for the cooperation and assistance in the preparation of this article rendered by Thomas G. Plant Company and United Shoe Machinery Corporation.

completed upper is then drawn to proper shape over a last and attached to the insole. The outsole is put on, the heel attached and finally the shoe is finished for the market. There are several types of processes but at the present time the Goodyear Welt Process is in most general use, while the McKay sewed, the Turned, and other processes are becoming less employed. We will follow through a pair of shoes made by the Goodyear Welt Process, only referring to other processes where they differ materially.

Design

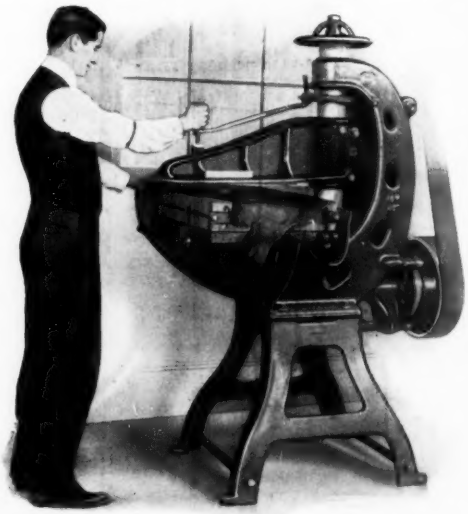
The first step in the procedure of manufacturing a shoe of new design is to make a model last incorporating the new ideas. In all ordinary shoes and even in feet there are certain fixed standard dimensions and relationships which have been accepted after considerable experience, and the last maker must conform to these regardless of his desires to make a new shape. He is greatly limited as to what changes he may make from other standard shapes. When the model last has been made in one standard size and width, lasts of other sizes and widths can be made from it by means of a "last turning" machine. This is a very ingenious machine of pantograph principle, in which a small roller or guide follows the lines of the model and transmits the motion to a small knife or tool cutting the new last. By setting a number of indicators to the size and width desired, the new last is automatically turned to a similar shape as the model last, but of proper size and width. Such a machine is made possible on account of the fixed relationships of dimensions mentioned above, but was only developed after long study and experimentation. After the last is shaped it must be furnished with a metal heel plate and a portion of it must be hinged so that it can easily be removed from the shoe after the latter is formed over it. This hinge operates along the principles of a toggle, so that by making a slight movement the pressure at the heel is quickly removed and the last can be withdrawn from the shoe without difficulty.

Besides the last, patterns must also be made which serve as guides in cutting the various pieces from which the shoe is assembled. Similarly, as in the case of the last, one model pattern is made, corresponding to a standard size and width for each separate piece of leather or cloth to be used. With it as a guide a pantograph "grading" machine cuts patterns for other sizes and widths according to the setting of the indicators. These patterns are then bound with metal for durability. Where the production of one type or style of shoe is large, light metal dies are made so that the pieces may be cut out more rapidly and accurately by means of a press or special machine for the purpose.

Cutting and Skiving

When an order is received in a factory, a number of dated tags are prepared, giving all the details as to lot number, quantity, sizes, widths, styles, material, method of manufacture, etc. These tags are sent to the various sources or departments where operations on the various parts begin. On receipt of his tag the stockkeeper lays out the material necessary and it is sent with its tag to the various cutting rooms where the proper patterns or dies are assembled.

Cutting is either by hand or machine. When by hand the metal bound patterns are used and a sharp knife on a wooden block quickly lines out the material. In the case of cloth linings and sometimes cheap leather outers a number are cut at the same time by a press using a die. The best leather parts, however, are cut singly



Courtesy of United Shoe Machinery Corp.

Fig. 1.—**Clicking Machine.** In this machine the pieces are cut by means of pressure momentarily exerted on a very light steel die placed on the leather. This is moved around in such manner as to give the maximum amount of leather from the hide, taking into consideration the purpose for which the cut piece is to be used.

Courtesy of T. G. Plant Co.

Fig. 2.—**Stitching Room.** In some of the larger plants, rooms of this size are devoted entirely to one operation.

even if a die is used. This is done on what is called a "clicking" machine, which is so arranged that the operator can inspect the leather carefully before cutting so that no faulty material is used. The operator also must use judgment in placing his die or pattern, as leather stretches differently in the various parts of the hide and along different directions. In cutting he must consider the future treatment the leather must undergo. The dies used in the "clicking" machine must be so light that the leather will not be injured in sliding over them.

The dies may be so constructed as to give match marks along the edge, or prick punches at various other points so that future operators can use them as a guide in assembling.

Some edges of the leather show in the finished product, so in order to give a neat appearance these edges are shaved off to make a wedge. The shaved portion is then covered with cement, folded and hammered down, either by hand or a machine. This is called skiving.

The ornamentations on tips, vamps, foxings, etc., are put in by small punching machines. There are several types of these, some doing the whole job at once while in the case of others the operator must direct the punch along a line or design. Before stitching the parts together, reinforcing strips are sometimes cemented in where most useful.

Stitching Room

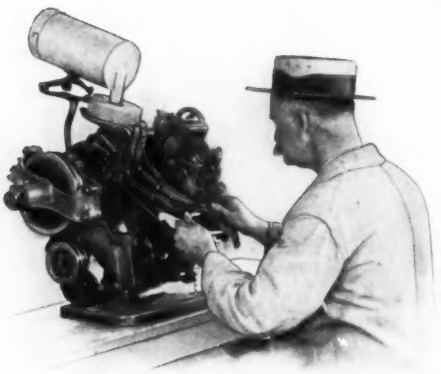
After all the parts of the upper are cut out they are tied together and sent to the stitching room where they are sewed together with extraordinary rapidity. Stitching may be divided among several different types of machines according to the quantity and type of work passing through. In some cases one bank of machines will simply do a single operation. The machines are arranged so that if desired four rows of stitching can be run at once, with white thread inside and black or colored thread outside. These stitchers make about 600 stitches a minute when run up to normal capacity. An interesting machine is the stitch rubber which smooths out what would otherwise be rough seams, as in the case where vamps, quarters or foxings join at the heel.

The next process is putting in the eyelets. Some machines do this on both sides at once, while others put the eyelets in singly, the two sides being matched together. As later on the upper must be drawn tightly over the last, it must be laced so as to give it the proper opening at the throat. This is done by a lacing machine which puts a cotton cord through all the eyelets nearest the throat of the shoe and ties a bow knot simply by one stroke of a lever.

The upper is now ready to receive its sole. This is done in the sole leather room.

Sole Leather Room

At the same time that an order tag was sent to the upper room, another was sent to the sole leather room where the outsoles, insoles, coun-



Courtesy of United Shoe Machinery Corp.

Fig. 3—**Eyeletting Machine.** In this machine the eyelets are quickly placed and riveted in the upper of the shoe.

ters, toe boxes and heels are made ready. Many manufacturers buy these parts already cut out in a separate factory, and just assemble them for their own work. Wherever made, they are cut to size on dieing out or "dinking" machines. Toe boxes and counters are formed to approximately the shape that will be required later.

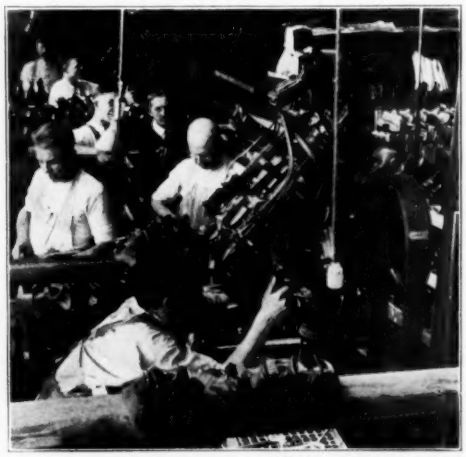
In order to toughen them, the soles are placed in a "rolling" machine where the fibres are condensed under great pressure. This procedure corresponds in effect to the hammering formerly given by the old time shoemaker in order to increase their wearing ability. If the soles are too thick or uneven they are reduced to proper thickness by a "splitting" machine. In order that the soles may be sufficiently soft and pliable to conform easily to the shape desired later on, they are placed in a special tempering room. Here the temperature and humidity are kept at just the right point to give the best results.

The insole is treated in a similar manner to the outsole, but in addition it is channeled. This process consists of cutting a slit about ½" wide diagonally inward around one edge or corner and turning up the thin edge or lip thus made at right angles to the sole. The machine that cuts this edge also cuts a small channel around the sole and on the surface, which serves as a guide in sewing the welt or inseam.

The proper last is then selected and its insole tacked to it. The lasts with insoles attached corresponding to the order are now placed on one or more shoe racks which are wheeled out to meet the uppers coming from the stitching room.

Lasting

Each upper is fitted over its proper last, the toe boxes and heel counters being inserted. The upper is then tacked temporarily in position to the last at the heel by two small tacks driven partly in. The last with its upper and insole is next passed to the "pulling over" machine. In this machine a number of pincers grasp the leather at different points on each side of the toe, and when a foot lever is pressed the leather



Underwood & Underwood

Fig. 4—**Pullerover.** In this machine the leather of the upper is grasped by a number of clips which the operator cause to be pulled over the toe of the last by pushing a lever. He can further manipulate the exact position of the upper, in relation to the last, by adjusting levers, and when finally satisfied as to the accuracy of the work, pushing his main lever again causes the upper to be tacked to the last in the proper position.

is drawn tightly over the toe. Its exact position can be further adjusted by the workman moving different levers, and when he is satisfied that the upper is properly placed, he pushes the foot lever again, which causes the pincers to wipe the leather around the toe. At the same time a number of tacks are driven partly into the last through the insole around the toe. This holds the upper firmly in the correct position.

The shoe is next passed to the "lasting" machine where the leather is drawn tightly and evenly around the last, so that when the operation is completed the leather is stretched equally in all directions. This machine has a set of pincers which grasps the material at one position, stretches it and drives tacks. It then repeats the operation until all the edge is tacked

Courtesy of United Shoe Machinery Corp.

Fig. 5.—**Lasting Machine.** In this machine the upper leather is given a uniform stretch around the last and tacked through the insole temporarily into position.

down. Lasting is a very important operation and the workman must use considerable judgment in making a perfect job. The leather is then drawn around the heel and toe by sets of friction wipers so that there are no wrinkles. After the leather is drawn around the toe it is held by a fine wire fastened on each side of the toe. The surplus leather keeps the wire from slipping. The heel is tacked down hard to the insole, the tacks clinching against the iron on the heel of the last.

The excess leather of the upper is next trimmed away and pounded out smoothly along the edge of the last. In the lighter grades of shoes the upper is stapled to the channel lip of the insole and the tacks withdrawn.

Welting

The shoe is now ready to receive the welt. In sewing the welt to the insole and upper, the needle only passes through the welt, upper and lining, and enters the insole so that no stitches protrude into the shoe, thus leaving a smooth surface for the foot. This is illustrated in Fig. 7. After the welt is sewed on, the insole tacks are all withdrawn by a machine, and the assembly is passed to a trimming machine where all the excess parts of the shoe upper, lining and welt are cut away almost down to the stitches. The welt is now beaten down with a "beating and slashing" machine so that welt stands out around the shoe and the latter is reasonably smooth across the bottom. As the welt leather is bent around the toe there is a tendency to draw along the outer edge. This is taken care of by a machine with a rapidly vibrating hammer which beats out the welt. It has a little knife which at the will of the operator, makes a series of short diagonal cuts along the edge.

The bottom is now evened up with a filler, usually of ground cork and rubber cement, and is ready to receive the outsole. Both the filling and outsole are coated with rubber cement and are ready for the next process, "sole laying."

Courtesy of United Shoe Machinery Corp.

Fig. 6.—**Welt Sewing Machine.** By this machine the welt is quickly sewed to the upper and insole, in the manner indicated in Fig. 7.

In this a heavy rubber pad formed to the desired shape of the shoes is used. The assembly of upper, last and insole with the outsole held in proper position, is pressed heavily into this pad and allowed to remain there a few minutes in order to permit the cement to set in proper position. The sole and welt are next trimmed with a "rough rounding" machine so that the sole protrudes the proper amount beyond the upper. At the same time a channel or slit is cut around the edge of the outsole and the lip thus exposed turned up as in the case of the insole. The shapely appearance and style depends in a great measure on the skill of the

workman with the "rough rounding" machine.

In order to make the shoe shapely and pliable, the edges of the sole in the shank are often bevelled away. The heel portion of the sole is next nailed securely, the nails clinching inside against the last. This portion of the sole is then trimmed. In the making of men's shoes the operations of nailing and trimming heel seats generally comes before rough rounding.

Sole Stitching

The outsole is now stitched to the welt by a very powerful and intricate machine, the stitches following the channel previously cut in the sole. The stitch used in this operation is of such a character and the thread so waxed and treated that the sole may wear down considerably without the sole and welt becoming separated.

Cement is next placed in the sole channel and the lip cemented down, covering the stitches. It is now ready to receive the heel. Before this is done, however, the shoe is passed through the "sole leveling" machine. In this a vibrating roller under very heavy pressure passes over the sole into the shank and around the edges, removing every possibility of there being any unevenness in the bottom of the shoe.

The heel is next nailed on without the top lift. In nailing the heel, the nails which have no heads are allowed to protrude slightly above the surface of the heel, so that the top lift can be finally simply pressed on, leaving no nail heads exposed. Before the top lift is pressed on, cement is placed on it in order to secure good attachment to the heel. As a protection against wear, brass slugs are driven around the back edge of the heel. The top lift has been cut to exact size before being put on and serves as a guide for trimming the heel, which is done by a "trimmer." The shank edge of the heel is trimmed by a "breasting" machine. This is adjusted very exactly by means of a finger so as to prevent cutting into the shank, and yet remove all surplus heel stock. Our shoe is now all shaped and ready for finishing.

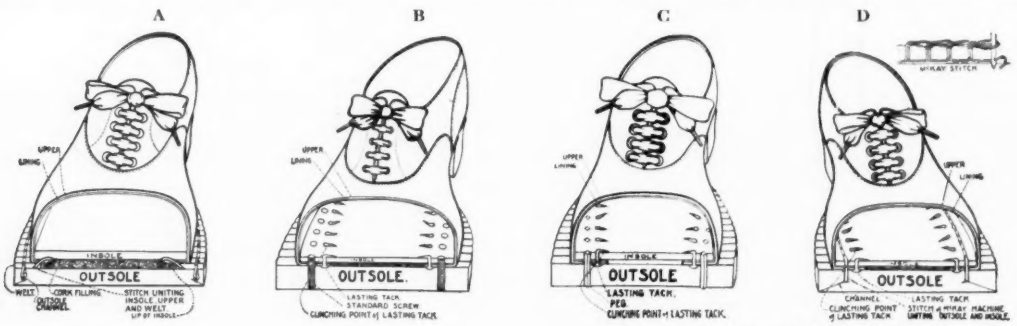
Other Processes of Manufacture

In the McKay process of sewing shoes there is no welt and the stitches between the outsole and insole appear inside the shoe. In this process the lasting tacks also are not removed and appear inside the shoe. See Fig. 7. This method of sewing is used more generally in the manufacture of the cheap and medium grades of shoes.

Screwed and pegged shoes are made similarly to the McKay method except that instead of the outsole and insole being sewed together they are screwed or pegged together. In the screwed shoe a coil of wire with continuous thread is used, which rotates so as to screw the wire through the leather. This is done by an interesting machine which has an automatic arrangement so that the screw is forced just so far through the leather and remains flush with the surface without protruding.

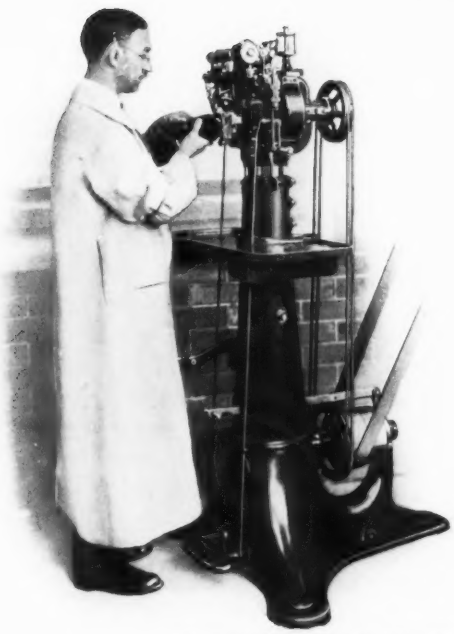
The pegged shoe is made similarly to the screwed shoe except beachwood pegs are used instead of screws.

The "turned" shoe is made wrong side out. It has no insole, the upper is sewed directly to the sole, both of which are inside out when placed on the last. After the surplus part of the shoe upper and lining have been trimmed the last is removed and the shoe is turned right



Courtesy of United Shoe Machinery Corp.

Fig. 7 —Cross-sectional view showing various types of shoe construction: A. Goodyear Welt Shoe. B. Screwed Shoe. C. Pegged Shoe. D. McKay Sewed Shoe.



Courtesy of United Shoe Machinery Corp.

Fig. 8.—**Rounding and Channeling Machine.** In this machine the excess leather on the outsole and welt are trimmed away so that they protrude a uniform distance from the edge of the shoe. A channel is also cut in the underside to hold the thread.

side out and lasted again. This type of shoe requires the very best leather, which must be light and flexible.

Finishing

A number of machines are necessary for finishing. The edges are cut and ground to proper shape and treated with hot wax which is burnished into the leather in order to give it a lasting finish. The sole is buffed to the desired finish. It is then blacked or colored and polished on various machines. The last which in the making of a Goodyear welt shoe, has remained in the shoe throughout all operations is now removed and the shoe is placed on a "treeing" machine. Here a form in the shape of the last but smaller is expanded to fill out the shoe snugly. All wrinkles are rubbed out and the shoe is given its final treatment before packing.

Lubrication

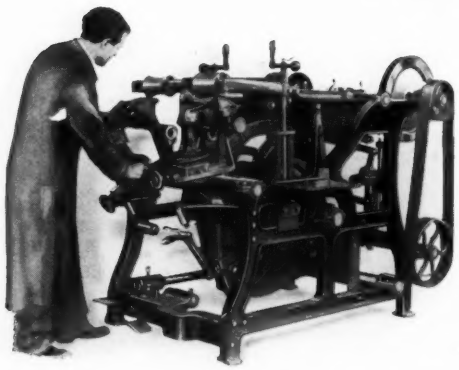
The machines used in the shoe industry contain in their intricate parts almost every kind of motion devised in mechanical engineering. They act almost human. To produce these motions and actions there are rubbing and sliding surfaces of all types with varying pressures and at vastly different speeds. To get minimum frictional resistance and hence least loss of power, an oil or grease should be selected which has just enough viscosity and oiliness to keep the metal surfaces from touching. But in every machine there are many different bearing pressures and if the above rule were applied strictly each machine might require a dozen different oils. This manifestly is impractical from an operating standpoint. Also there should be a factor of safety in oiling. It is much better to use an oil a little more heavy or viscous than

Courtesy of United Shoe Machinery Corp.

Fig. 9.—**Outsole Stitching Machine.** In this machine the outsole and the welt are stitched together with a lock stitch that does not pull out readily even though the sole is well worn away. After stitching, the channel on the sole is cemented down to cover the stitches.

is absolutely necessary, than to run the risk of a stuck bearing and a laid up machine. The lubricating engineer should aim to satisfy all the requirements of a machine with as few oils as possible—only one if practical—for oils look more or less alike and are apt to get mixed. This same reasoning may be made to apply to a whole room or bunch of machines, so the final recommendation in any particular case may depend on the layout of the factory.

In general, machines which have heavy bearing unit pressures and slow rubbing speeds, require an oil of 300″-500″ viscosity Saybolt at 100° F. or a medium grade of grease. This



Courtesy of United Shoe Machinery Corp.

Fig. 10.—**Sole Leveling Machine.** In this machine very heavy pressure is applied to the sole so as to roll out any unevenness.

applies to such machines as Sole Leveling, Jack Rollers, large Splitters, Insole Tackers, etc. If the speed is slow but the pressures are low, an oil of 180″-300″ viscosity can be used. Examples: Inking Machines, Breasters, Clicking Machines, Pull Overs, etc.

As rubbing speeds of shafts or surfaces increase, oils of less viscosity are practically applicable. In this type of machine an oil of 150″-200″ viscosity is sufficiently heavy to take care of all the requirements. Examples: Skivers, Stapling Machines, Channeling and some Trimming Machines.

With machines running at very high speed, as Edge Trimmers, or those where pressures are small, as Upper Stitchers, the viscosity of the oil need not be over 150″ Saybolt, but one of 180″ will do no harm.

In cases where oil may fly and injure the fabric it is often advisable to use a grease instead of an oil, even though the latter would be more efficient.

The use of a vegetable or animal oil is not recommended as most of such oils when exposed to the air oxidize to form a gummy substance which clogs oil holes and bearings. Only a well refined mineral oil should be used but it should be applied systematically. This latter perhaps is the salient feature of shoe machinery lubrication. The thousands and thousands of bearings must be kept well lubricated and it should not be left to haphazard methods. Usually an operator is required to keep his own machine well oiled, with the general result that it is over-oiled and there is not only a waste but the machine and surrounding floor are oil soaked. This oil takes up dust and dirt, forming a gum which not only may plug up oil holes but also gets on the hands and clothing of operators and from them to the fabric. The problem therefore is to keep machines well oiled but not over-oiled, and care should be taken to impress this upon the operators. If properly handled it is believed that all machines can be lubricated by two or three oils of varying viscosity, and one or two greases. An oil of 180″ 200″ viscosity should take care of light machinery, and one of 450″-500″ of heavy machinery. Another oil of about 300″ viscosity also would be found advisable for medium speeds and loads. If these oils are made right the results will be right. A light bodied grease and a gear compound should take care of the cases where the use of grease is essential.

Conclusion

In many industries the introduction of machinery to replace hand labor has resulted in the employment of a less skilled type. In shoe making this is not true. It takes more skill to run a shoe machine properly than it did to make a pair of shoes in olden times. The final perfection of product is dependent on each operator, and the efficiency of the whole organization depends on each unit. Inspection, "crownings," are frequent and an inefficient worker is soon weeded out. In similar manner the production by every machine is dependent on the proper running of each of its parts, and every bearing surface is dependent on correct lubrication.

Courtesy of United Shoe Machinery Corp.

Fig. 11.—**Shoe Tree.** After the shoe is completed, the last is removed and the shoe is placed on a shoe tree and any imperfections or roughness are smoothed out and the shoe finally made ready for packing

Flow of Oil in Pipes

IN THE July, 1920 issue of LUBRICATION there was a partial discussion of the fundamental principles underlying the rate of flow of oil in pipe lines and two tables were given to assist anyone in calculating the approximate pressure necessary to force oil through different sizes of pipes at certain definite rates. These tables were based on the data available at that time and considered both the case of viscous or straight line flow and turbulent flow. If, in flowing through a pipe the oil followed the viscous flow law, that is, if the velocity was sufficiently low that the liquid flowed like a large number of concentric tubes without intermixing, a certain definite formula, Poisseuille's Equation (see Fig. 1), held with fair accuracy. This equation simply said that the pressure necessary to force oil through a definite length of pipe was directly proportional to the velocity and viscosity of the liquid and inversely proportional to the area of the pipe cross-section opening.

When, however, the velocity reached a certain critical value or region the liquid became turbulent and acted like a lot of balls rolling over each other. In this case Poisseuille's equation did not hold, and several attempts had been made to formulate the pressures necessary but these did not agree very closely with each other.

Some recent work carried on at the Massachusetts Institute of Technology* has greatly cleared these discrepancies and given us a method of calculation much simpler than any previous one. It was shown that one formula could be used to cover practically all cases, provided the constant was varied according to a fairly definite law. This equation originally developed by Fanning is as follows:

$$p = \frac{K f l s v^2}{D}$$

p = Pressure; f = a variable friction factor; l = length; s = Specific Gravity of liquid; v = Velocity of liquid and D = Diameter of pipe. K is a constant depending on units used and not on independent functions of all four variables as has been generally assumed. It was shown by Blausius in 1912 that f was a function of $\frac{D v s}{z}$ where z is the absolute viscosity of the liquid. In the case of viscous flow the relationship followed the simple law $f = 0.00207 \frac{z}{D v s}$ which if substituted in Fanning's equation gave that of Poisseuille. In the region of turbulent flow, however, the relationship was not so simple but it was definite; that is, for every value $\frac{D v s}{z}$ there was a definite f. Therefore by calculating $\frac{D v s}{z}$ for any particular case f was determined, which, substituted in Fanning's equation, gave the correct value of the pressure drop.

Messrs. Wilson, McAdams, and Seltzer made a large number of determinations of f from their own data on several sizes of pipes and various viscosities of oils and at different velocities. These values were plotted on a chart similar to Fig. 1. All the reliable available data from other experiments on gases and liquids were plotted also, and found to agree reasonably well with their own experiments, so this can be now considered to be the latest word on flow of oil.

It is to be noted in this plot that in the turbulent flow region the value of f varies according to the condition of the inner surface of the pipe. This was to be expected but with a little judgment an engineer should have no difficulty in getting true values.

Elbows

Messrs. Wilson, McAdams and Seltzer also determined the effect of Elbows upon the pressure drop in a line of pipe. "The most convenient method of expressing the frictional resistance due to an elbow of a given size is in terms of "equivalent length" of straight pipe which will give the same resistance to the flow of a given liquid." It has been found practical to

* The Flow of Fluids through Commercial Pipe Lines. By Robert E. Wilson, W. H. McAdams and M. Seltzer, *Jour. of Industrial and Eng.*, Vol. 14, No. 2, p. 105.

Chart for Determining Friction Factors used in Computing Fluid Flow in Pipes.

Curves copied from charts furnished by Research Laboratory of Applied Chemistry, Massachusetts Institute of Technology.

Formula for computing pressure necessary to force Fluids thru Pipes.

$$p = \frac{0.323\, f\, l\, s\, v^2}{D} = \frac{0.0538\, f\, l\, s\, Q^2}{D^5}$$

p = pressure drop in lbs. per sq. in.
f = friction factor (Fanning)
l = length of pipe in feet
s = specific gravity referred to water
D = Inside pipe diameter in inches
Q = flow in gallons per minute

v = average linear velocity in pipe line (ft. per sec.) $= \frac{0.408Q}{D^2}$

z = absolute viscosity in centipoises = kinematic viscosity x specific gravity

Kinematic viscosity may be determined from tables or approximately by formula $K = 0.216\,T - \frac{180}{T}$ where T = Saybolt time in seconds.

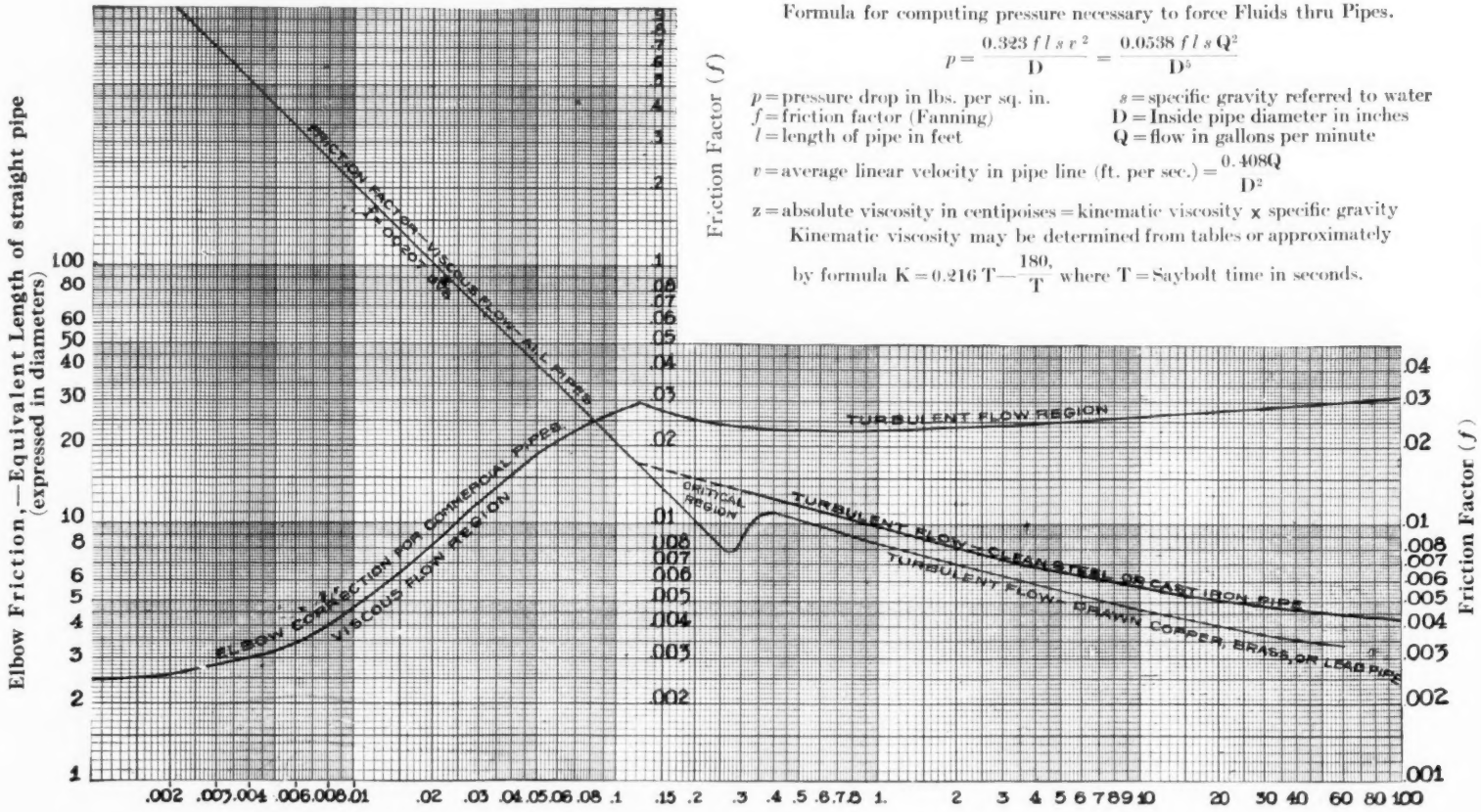

Elbow Friction,—Equivalent Length of straight pipe (expressed in diameters)
Friction Factor (f)
FRICTION FACTOR—VISCOUS FLOW—ALL PIPES
f = 16/N
ELBOW CORRECTION FOR COMMERCIAL PIPES
VISCOUS FLOW REGION
CRITICAL REGION
TURBULENT FLOW REGION
TURBULENT FLOW—CLEAN STEEL OR CAST IRON PIPE
TURBULENT FLOW—DRAWN COPPER, BRASS, OR LEAD PIPE
Friction Factor (f)
D vs / z

Fig. 1

express this as a function of the modulus $\frac{D\,v\,s}{z}$ and the average resulting curve from many experiments is shown in Fig. 1. The ordinate in this plot shows the number of pipe diameters which must be added to a length of pipe to allow for the effect of each elbow. This is computed against the value of $\frac{D\,v\,s}{z}$ which an engineer will have computed already in determining f.

Methods of Calculation

"The calculation of the pressure drop through a pipe line under any specified set of conditions is a very simple matter. The steps involved may be outlined as follows:

1. Calculate the value of $\frac{D\,v\,s}{z}$ (or its equivalent, $0.408\ \frac{Q\,s}{Dz}$ if Q is known rather than v) for the fluid and pipe in question. If there is any uncertainty as to the measurement or estimation of any of the quantities, see the subsequent section on determination of the known quantities.

2. By referring to Fig. 1 find the value of f which corresponds to this value of $\frac{D\,v\,s}{z}$ using the curve corresponding to the degree of roughness of the pipe in question. For values of $\frac{D\,v\,s}{z}$ less than 0.002, extrapolations on the straight 45° line for viscous flow may readily be made by dividing the abscissae by 10 (or 100) and simultaneously multiplying the ordinates by 10 (or 100).

3. Using the same value of $\frac{D\,v\,s}{z}$, refer to Fig. 1 for the equivalent length of straight pipe corresponding to each 90° elbow. Multiply this by the number of elbows, convert the correction from pipe diameters into feet, and add it to the length of straight pipe. (Note that two elbows very close together, or a return bend, have less effect than two elbows some distance apart.)

4. Insert this value of f in the modified Fanning equation, $p = 0.323\frac{f\,l\,s\,v^2}{D}$ or its equivalent, $p = 0.0538\frac{f\,l\,s\,Q^2}{D^5}$, and obtain the pressure drop directly. This method and this formula should be used regardless of whether the liquid is in viscous or turbulent motion."

"The foregoing procedure must, of course, be slightly modified in case the permissible or available pressure drop is known and it is desired to calculate any one of the other five quantities which may be unknown in a given practical problem." The factors used in the Fanning equation are all easily computed with little danger of error except perhaps the specific gravity (s) and viscosity (z.)

Specific Gravity

"The value of specific gravity, s, must be expressed in units relative to water at 39° F. (temperature of maximum density). In other words, it is equivalent to the true density in grams per cc. Specific gravity figures are frequently given relative to water at some other temperature than 39° F. (4°C.) and hence are subject to some slight correction to give the proper value of s for use in the foregoing equations."

Viscosity

The factor viscosity (z) in this article is the absolute viscosity and is expressed in centipoises. In order to obtain absolute viscosity both the Saybolt viscosity and the specific gravity must be known. There are a number of tables giving the relationship between Saybolt time and kinematic viscosity, which is absolute viscosity divided by specific gravity. See LUBRICATION, June, 1921. One formula recently developed is

$$\text{kinematic viscosity} = 0.216\ T - \frac{180}{T}$$

where T = Saybolt time in seconds.

Velocity

"Velocity should be expressed in feet per second, and means the effective average velocity in the pipe, obtained by dividing the rate of discharge in cubic feet per second by the cross-sectional area of the pipe in square feet. Data may be transposed from gallons per minute to velocity in feet per second, or vice versa, by the conversion formula $v = \frac{0.408\ Q}{D^2}$

Limitations of Method

"The data and methods of calculation given in this article cover substantially the entire field of the flow of all fluids, including gases and dry vapors, through commercial pipe lines. There are, however, a few exceptions which should be carefully noted before attempting to use the formula in certain special cases. These may be specified as follows:

1. The method is not directly applicable to the flow of gases where the drop in pressure along the pipe line is more than 10 or 15% of the final *absolute* pressure, because the density and velocity of the fluid are thereby changed. If, however, average values are used for the density and velocity, instead of the initial or final values, this formula may be used for pressure drops up to 40 or 50% without serious error.

2. The method is not applicable to flow through short sections of pipe opening into large chambers where the entrance and exit losses are appreciable in comparison with the friction losses through the pipe. These losses become inappreciable when the pipe is more than 1000 diameters long, and may generally be neglected for approximate calculations for lines longer than 300 diameters.

3. The method is not applicable to the flow of semi-solid plastic materials, such as asphalt, clay suspensions, very viscous colloidal solutions, etc., where the laws of flow are modified by the tendency of the material to behave like a solid under certain conditions. However the curves apply to certain crude oils four thousand times as viscous as water at room temperature.

4. Precautions must be observed and highly accurate results cannot be expected in cases: (a) where the pipe is badly corroded or tuberculated, and the apparent value of f may increase to double that given in the formula, owing partly to a decrease in the effective cross-sectional area; (b) where a hot oil is passing through a pipe line with viscous flow motion, and the existence of a large temperature gradient from the inside to the outside makes accurate calculations practically impossible; and (c) where there is any tendency to precipitate out solids (such as paraffin wax) on the walls or in the bottom of the pipe lines.

"With these exceptions it is believed that the recommended method of calculation is applicable to an entirely satisfactory degree of accuracy to all commercial problems involving the flow of fluids through pipe lines."

Flow of Oils Through Commercial Pipes

Size of Pipe and Av'ge Inside Dia. inches	Capacity Gals. per Minute	Pressure in lbs. per square inch per 100 feet of pipe based on Oils of 20° Baume Gravity — VISCOSITY IN SAYBOLT SECONDS					
		100	200	300	400	500	600
	2	6.59	14.3	21.7	29.1	36.9	43.6
½″	5	21.1	34.8	53.4	71.5	89.5	107.0
.622	7	37.7	49.2	74.6	101.0	129.0	152.0
	10	69.8	85.8	107.0	144.0	177.0	217.0
	15	143.0	174.0	194.0	217.0	267.0	325.0
	2	2.16	4.74	7.04	9.48	11.6	14.2
¾″	5	5.6	11.5	17.1	23.1	28.9	35.2
.824	7	9.96	16.1	24.5	32.8	40.5	48.9
	10	18.4	22.3	34.9	46.0	58.5	70.9
	15	37.9	45.7	51.5	70.4	88.3	106.0
	5	2.06	4.32	6.68	8.85	11.0	13.4
1″	10	5.9	8.74	13.4	17.9	22.0	26.6
1.05	15	11.9	14.5	19.7	26.6	33.2	40.3
	20	19.7	23.8	26.8	35.4	44.1	53.5
	25	29.0	35.1	39.3	44.2	54.5	66.8
	10	.783	1.57	2.40	3.22	3.98	4.86
1½″	20	2.61	3.17	4.85	6.52	8.02	9.70
1.61	30	5.30	6.43	7.15	9.68	12.1	14.7
	40	8.72	10.6	11.9	12.8	16.0	19.4
	50	12.7	15.7	17.4	18.8	19.8	24.2
	10	.266	.578	.875	1.17	1.47	1.79
2″	20	.79	1.15	1.75	2.34	2.92	3.52
2.067	30	1.60	1.93	2.62	3.50	4.40	5.30
	40	2.63	3.18	3.56	4.66	5.85	7.10
	50	3.86	4.68	5.28	5.88	7.26	8.85
	50	.174	.198	.307	.412	.494	.612
4″	100	.550	.668	.744	.810	1.01	1.22
4.026	150	1.09	1.36	1.50	1.62	1.74	1.84
	200	1.81	2.22	2.49	2.68	2.85	2.98
	250	2.67	3.26	3.67	3.97	4.20	4.41
	100	.0788	.0956	.115	.158	.194	.236
6″	200	.259	.315	.359	.388	.408	.480
6.065	500	1.27	1.55	1.74	1.88	2.01	2.20
	700	2.29	2.80	3.15	3.36	3.60	3.78
	1000	4.24	5.21	5.82	6.32	6.68	7.05
	200	.0696	.0834	.0947	102	.128	.155
8″	500	.340	.418	.459	.500	.530	.556
8.03	1000	1.13	1.37	1.55	1.67	1.78	1.87
	1500	2.27	2.74	3.07	3.30	3.59	3.75
	2000	3.88	4.55	5.15	5.56	5.92	6.22
	1000	.165	.203	.228	.242	.258	.272
12″	2000	.552	.670	.750	.810	.866	.906
12.05	3000	1.15	1.34	1.50	1.63	1.73	1.83
	4000	1.91	2.22	2.50	2.69	2.84	3.00
	5000	2.90	3.34	3.68	3.97	4.22	4.41

To change capacities from gallons per minute to barrels [42 gals.] per hour multiply pressures by 1.43. To change from pressures per square inch per hundred feet to pressures per square inch per mile multiply by 52.8.

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